NEW AGE WATER CHILLERS WITH WATER AS REFRIGERANT

J. Kühnl-Kinel
ST Division – Cooling and Ventilation Group (ST/CV)
CERN, Geneva, Switzerland

Abstract
Vacuum-process technology producing chilled water needs no refrigerant of the conventional kind, but water from the process itself is used to generate cooling. This eye-catching novelty incorporates many of the considerations about the future of refrigerants: "ozone friendly", no extra demands for safety measures or for skilful operators, no special requirements concerning the installation's components, lower maintenance costs since leakages can be accommodated from the system. Vacuum-process technology may be used not only for production of chilled water but also for Binary Ice – pumpable suspension of minute ice crystals in an aqueous solution. This means that all the advantages related to a latent heat system may become available.

1. INTRODUCTION

The search for alternatives to refrigerants, which have ODP (Ozone Depletion Potential) or GWP (Greenhouse Warming Potential) leads eventually and inevitably to the so-called "natural" refrigerants. These are, by definition, substances which have no adverse effects on the ecological balance of our planet and are part of the natural environment. Such substances which are practically available today are ammonia, hydrocarbons, air, carbon dioxide and – last but not least – water.

Irrespective of some major differences to commonly known refrigerants and some of the indisputable disadvantages of water, the technology of cooling with water as refrigerant is state-of-the-art today and is utilized already for water chilling, ice making and heat pumps.

2. BRIEF TECHNOLOGY DESCRIPTION

Vacuum cooling systems producing chilled water or binary ice can be executed in different ways depending on the available energy source. The process is generally done under vacuum conditions which are governed by the required temperature of the fluid (water) to be cooled.

Figure 1 shows the schematic of vacuum water chiller. Water is injected into vacuum vessel (evaporator vessel) and is cooled by direct contact flash evaporation. When working under triple point conditions, binary ice (vacuum ice) is generated, which is pumpable ice-slurry. The amount of water to be evaporated is indicated in Table 1 and called "Evaporation Rate". It shows how much evaporating water generates the required amount of chilled water or Vacuum Ice [1].

The cold water vapour generated is removed from the evaporator vessel. This can be done in different ways, the principles of which are sublimation or compression and condensation. An intrinsic characteristic of water processes is the very large volume of water vapour that has to be handled. Despite of the superior evaporating enthalpy, the extremely large specific volume of water at low temperatures necessitates enormous flows.

The swept volume of a water vapour compressor has to be some 500 times higher than for a conventional refrigerant. Water yields only 340 kW of refrigeration for swept volume of 100.000 m^3/h. The driving energy can be selected to be mechanical (electricity), thermal (heat or steam), or combinations thereof. The present document describes only electrical powered machines since the other may only become interesting in special cases and under special circumstances which are not typical for CERN.

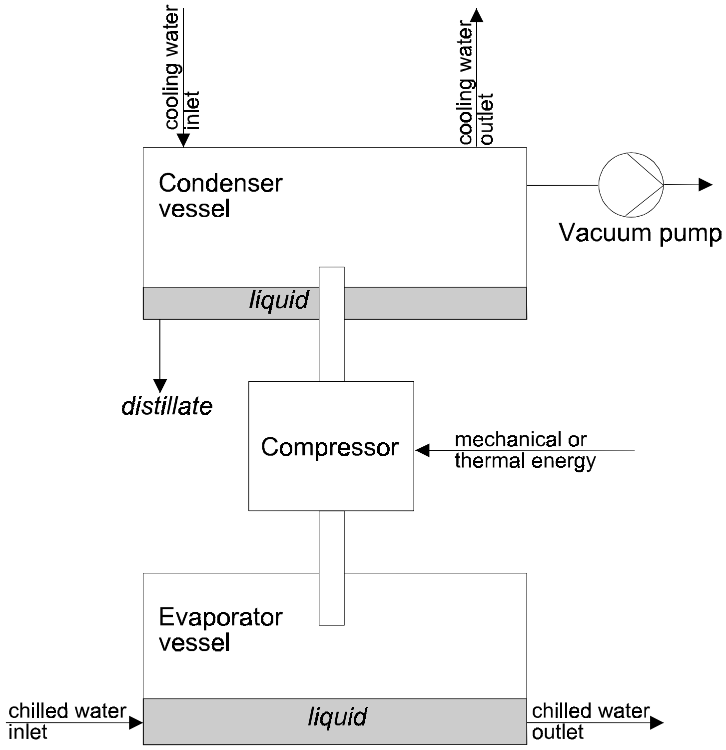

Fig. 1 Principle design of a vacuum water chiller.

The “beauty” of the vacuum technology lies in the possibility to cool any kind of water (even polluted), generate binary ice, and work fully with water as refrigerant.

Table 1

Water evaporation rate of vacuum cooling

		Enthalpy	**Evaporation Rate**
Evaporation		2500 kJ/kg	
Water chilling	$\Delta T_{inlet/outlet} = 3$ K	12 kJ/kg	0.5 %
	$\Delta T_{inlet/outlet} = 3$ K	25 kJ/kg	1.0 %
	$\Delta T_{inlet/outlet} = 3$ K	37 kJ/kg	1.5 %
	$\Delta T_{inlet/outlet} = 3$ K	50 kJ/kg	2.0 %
Ice generation		330 kJ/kg	13.0 %

Generally, the pressure lift for vacuum cooling systems is very little (some 20÷50 mbar). Depending on the application, however, the pressure ration of a water vapour compressor needs to be high and, in such cases, the vacuum water chillers are usually equipped with one, two or more compression stages. Using two compression stages, the steam is intercooled after the first compression stage which improves the COP (Coefficient of Performance). Both compression stages can be automatically and continuously adapted to the operating conditions of the refrigerating machine by frequency controlled motors. Table 2 shows the typical pressure ratios for different applications [2].

Table 2

Duties of vacuum cooling systems

	Fluid temperature	**Condensing temperature**	**Pressure ratio**
"Light Duty":			
Cooling ceilings	14 ºC	28 ºC	2.5
Cooling ceilings	14 ºC	35 ºC	3.5
"Normal Duty":			
Water chiller	6 ºC	28 ºC	4.3
Water chiller	6 ºC	35 ºC	6.2
"Heavy Duty":			
Vacuum ice machine	0 ºC	28 ºC	7.6
Vacuum ice machine	0 ºC	35 ºC	11.2

Even the "normal duty" systems show already significant pressure ratio demand which is difficult to meet with a single stage mechanical compressor. Axial compressors manage today a pressure ratio of 1.4 per stage, which necessitates compressors with 3÷8 stages for the duties, as per Table 2. Radial machines with a pressure ratio of 2.3 work with 1÷3 stage compression; however, the space requirements are unfavourable and are, in most cases, not practical.

3. ENERGY ASPECTS OF REFRIGERANT PLANTS WITH "WATER AS REFRIGERANT"

Since refrigeration plants with water as refrigerant require no heat transfer surface in the evaporator but are working with direct contact evaporation, the temperature of evaporation is the highest of all cooling systems. The same applies for condensation which can take place in a direct contact condenser that needs again no heat exchanger surface and yields therefore the lowest possible condensing temperature.

An "empty" vessel as condenser can accommodate very high flow rates, which makes it possible to operate with low temperature difference between inlet and outlet. This gives an additional reduction of the condensing temperature and increases the overall economy of the water cooling process.

It is possible to increase the COP of refrigeration systems with water as refrigerant by a factor of 2 or even more, especially when it comes to small temperature lifts where conventional compression systems with common refrigerant are limited by the minimal pressure ratio possible (Figure 2).

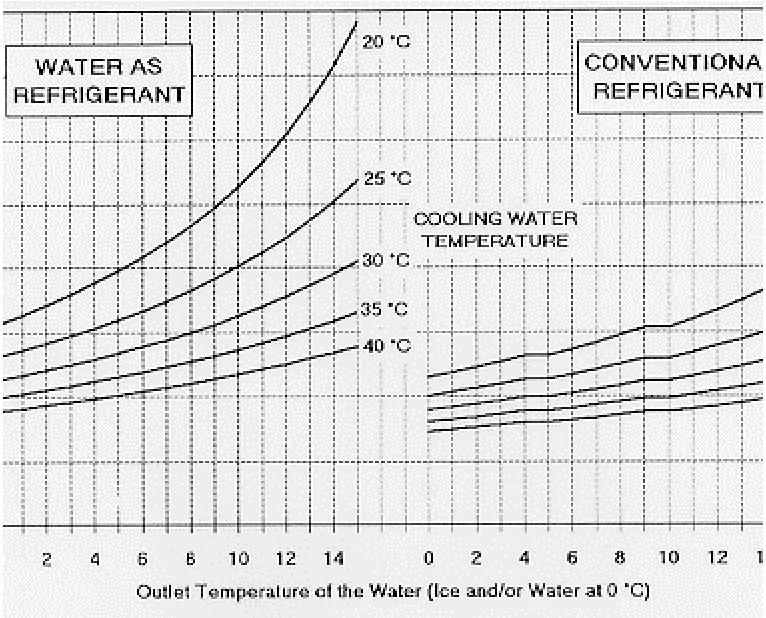

Fig. 2 Comparison of the COP for vacuum machines and conventional water chillers [4].

4. SUMMARY

Vacuum cooling systems using only water as refrigerant may become a prime substitute to conventional refrigerating processes. Although there are already many vacuum cooling installations all over the world with some 40 MW installed in ice makers, water chillers and heat pumps, this technology is still considered as relatively new, without "years of experience". The future will show which tendency in cooling science will be chosen, but we can already say that vacuum-water chillers remain among the most attractive solutions regarding its advantages as well as disadvantages:

Advantages:

- Only water as refrigerant which is cheap, environmentally neutral, without any safety risks, suitable for any location,
- No eventual risk of future developments of different laws and regulations,
- Supreme energy efficiency higher than that for conventional cooling machines,
- Quality of chilled water is of minor importance,
- Possibility of producing vacuum ice,
- Good part load characteristics due to variable motor frequency,
- No pressure-vessel regulations must apply,
- Lower maintenance costs since leakages can be accommodated from the system,
- No extra demands for safety measures or for skilful operators,
- No special requirements concerning the installation's components.

Disadvantages:

- Higher investment cost (about 200% of a conventional water chiller),
- Bigger overall dimensions,
- increased machine's room size since at least 1 m under floor is required for the right operation of the chilled water pumps.

REFERENCES

[1] J. Paul, "Binary Ice as a Secondary Refrigerant", Proceedings IVb of the 19th International Congress of Refrigeration, Den Haag, The Netherlands (1995).

[2] J. Paul, "Water as Refrigerant", Proceedings IVb of the 19th International Congress of Refrigeration, Den Haag, The Netherlands (1995).

[3] J. Kühnl-Kinel, "Study on the possibility of using the Binary Ice system for CMS and ATLAS experiments at CERN", Geneva, June 1996.

[4] E. Jahn, D. Lausen and J. Paul, "Cooling of Mines with Vacuum Ice", Proceedings of the FRIGAIR'96 Conference, Johannesburg, South Africa (1996).

[5] W. Salzmann Ltd. Catalogue "R718 Aqua Turbo Water Chiller".

BIBLIOGRAPHY

M. Rubik: "Chlodnictwo w instalacjach klimatyzacyjnych", Wydawnictwo Politechnika Warszawska, Warsaw, Poland, 1984.

Recknagel, Sprenger, Honmann, Shramek, "Poradnik - Ogrzewanie I klimatyzacja, z uwzgle dnieniem chlodnictwa i zaopatrzenia w ciepla wode", tlumaczenie polskie - EWFE, Gdansk, Poland, 1994.

APPENDIX 1 – R718 AQUA TURBO WATER CHILLER

Fig. 1 Scheme of the 2 stage R718 Aqua Turbo water chiller

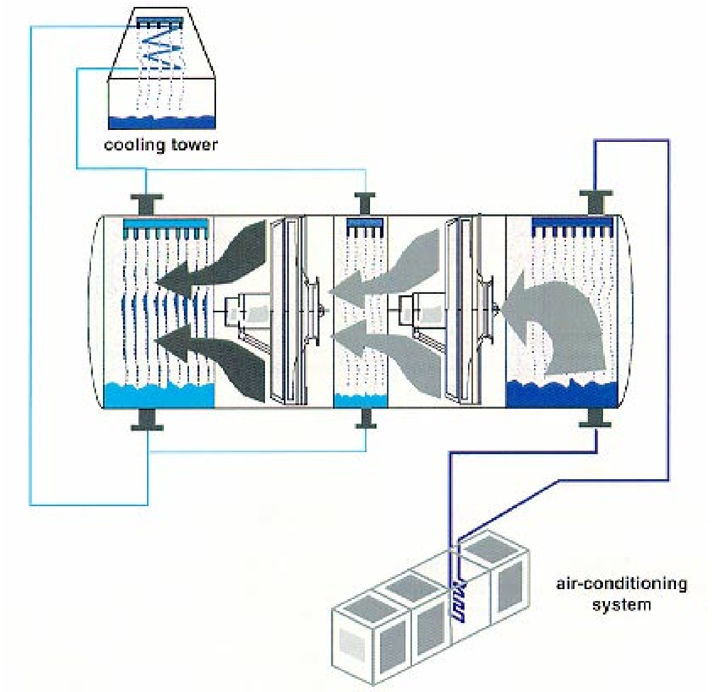

Fig. 2 View of the 2 stage R718 Aqua Turbo water chiller